SPONGE MEDIA DRYING USING A SWIRLING FLUIDIZED BED DRYER

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ABSTRACT

Surface preparation today has seen the introduction of sponge media as an alternative product against the traditionally used abrasive materials. Being soft and elastic, the sponge media reduces air borne emission significantly during surface preparation with capability to be re-used. However the environmental conditions limit the sponge media usage whereby wet surroundings prohibit the re-use of the sponge without being dried properly. This study proposes the swirling fluidized bed dryer as a novel drying technique for sponge media. Batch experiments were conducted to study the bed's hydrodynamics followed by drying studies for three bed loadings of 0.5 kg, 0.75 kg and 1.0 kg at three drying temperatures of 80°C, 90°C and 100°C. It was found that, minimum fluidization velocities for the wet sponge particles were found to be 1.342, 1.361 and 1.382 m/s with minimum swirling velocities of 1.400, 1.469 and 1.526 m/s. Drying times were recorded between 6 to 16 minutes depending on bed loading and drying temperature. Smaller bed weights exhibits faster drying with constant-rate drying period while higher drying temperature and larger bed load resulted in falling-rate drying period. Thin layer modelling for the falling-rate region indicates that Verma et. al model provides the best fit for the present experimental data with coefficient of determination, R^2 = 0.98773, root mean square error, RMSE = 0.05048, residuals = 0.3442 and reduced chi-square, χ^2 = 0.00254. The effective diffusivity, D_{eff}, for 0.5 kg bed load was found to be 3.454 x 10^{-9} m^2/s and 1.751 x 10^{-9} m^2/s for 0.75 kg bed load. In conclusion, SFBD was found to be a viable and efficient method in drying of sponge media for various industrial applications particularly surface preparation.

ABSTRAK

Penyediaan permukaan pada hari ini telah memperkenalkan media span sebagai produk alternatif berbanding kaedah tradisional yang menggunakan bahan pelelas. Bersifat lembut dan kenyal, media span mengurangkan pelepasan bahan berbahaya dengan ketara semasa penyediaan permukaan dan boleh diguna semula beberapa kali. Walau bagaimanapun keadaan persekitaran menghadkan penggunaan media span di mana persekitaran yang basah menghalang penggunaan semula span tanpa dikeringkan dengan baik. Kajian ini mencadangkan pengering lapisan terbendalir berpusar sebagai teknik pengeringan baru untuk media span. Beberapa eksperimen telah dijalankan untuk mengkaji sifat hidrodinamik diikuti dengan kajian pengeringan untuk tiga berat iaitu 0.5 kg, 0.75 kg dan 1.0 kg pada tiga suhu pengeringan 80°C, 90°C dan 100°C. Didapati bahawa, halaju minima terbendalir bagi span basah adalah 1.342, 1.361 dan 1.382 m/s dan halaju minima berpusar adalah 1.400, 1.469 dan 1.526 m/s. Masa pengeringan yang direkodkan adalah di antara 6 hingga 16 minit bergantung kepada berat media dan suhu pengeringan. berat media yang lebih rendah menunjukkan pengeringan lebih cepat dengan keadaan pengeringan kadar-tetap manakala suhu pengeringan yang lebih tinggi dan berat media yang besar menuruti keadaan pengeringan kadar-kejatuhan. Permodelan matematik bagi keadaan pengeringan kadar-kejatuhan mendapati bahawa model Verma et. al menunjukkan penyesuaian lengkung terbaik untuk data eksperimen dengan pekali penentuan, R^2 = 0.98773, ralat punca min kuasa dua, RMSE = 0.05048, residual = 0.3442 dan pengurangan chi-kuasa dua, χ^2 = 0.00254. Keberkesanan resapan, D_{eff}, untuk berat 0.5 kg adalah 3.454 x 10^{-9} m^2/s dan 1.751 x 10^{-9} m^2/s untuk berat 0.75 kg. Kesimpulannya, kaedah pengeringan lapisan terbendalir berpusar didapati amat sesuai bagi pengeringan media span.

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LIST OF SYMBOLS AND ABBREVIATIONS

MR	moisture ratio
SFBD	swirling fluidized bed dryer
RMSE	Root Mean Square Error
D_{eff}	effective diffusivity
d_m	average diameter
dM/dt	drying rate
M_e	equilibrium moisture content
R^2	coefficient of determination
Re_p	particles Reynolds number
U_{mf}	minimum fluidization velocity
U_{ms}	minimum swirling velocity
V_s	superficial velocity
ΔP_b	bed pressure drop
ΔP_d	distributor pressure drop
χ^2	reduced chi-square
ε	bed voidage

CHAPTER 1

INTRODUCTION

1.0 Background

Industrial surface preparation for corrosion protection is vital in many heavy industries such as marine engineering, automotive engineering, oil and gas, power plants and many more. With the evolving nature of engineering and advent of high-tech machineries and equipments, the industrial surface preparation process has also undergone much sophistication. One such sophistication is the utilization of sponge media as blasting material, replacing the traditional abrasive material used in the process.

This revolutionary concept of industrial surface preparation provide distinct advantages such as low dust/airborne particle produced during the process hence requiring minimal containment, flexibility of preparation, recyclability, safer working area and wider range of operation. These sponge media are open-celled and some are water based polyurethane impregnated with abrasive material. As a result, it provides inherent cost and time saving benefits. The physical characteristic of sponge media allows its particles to flatten upon impact and absorbs the energy before leaving the surface. As such, the media constricts pulling and encapsulating what would normally have become airborne contaminants [1].

The concept of sponge media blasting is shown in Figure 1.1. First, high pressure air from compressor is directed into the blasting nozzle containing sponge media. When this blasting nozzle is directed towards the surface to be prepared, the sponge media is released at high velocity. As a result, the chunks of sponge media hit the surface, and transfer the impact energy. In a matter of few micro-seconds, the sponge media flattens and suppresses the surface to scrap the unwanted surface before falling on the ground with the debris [1].

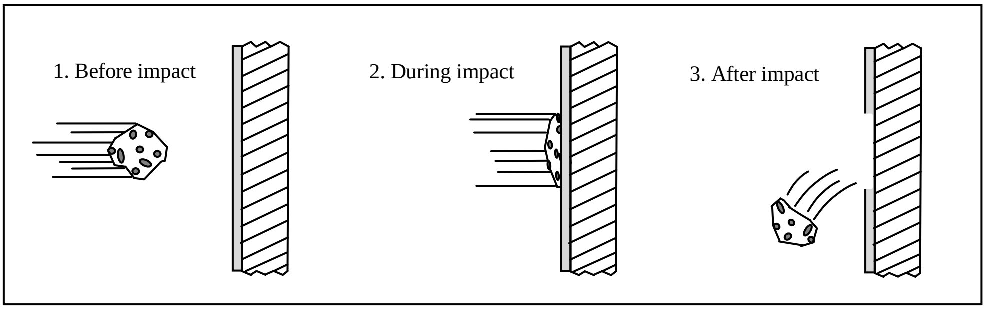

Figure 1.1: The sponge media blasting concept [1]

However, using this sponge media in wet and humid and surrounding imposes additional challenge in the surface preparation process. Just like a domestic sponge, these sponge particles readily absorb moisture and under wet surroundings, it can't be re-used without drying it first. Therefore, large inventory of these sponge media is usually required when surface preparation takes places in rainy seasons as the present drying method of wet sponge media is very inefficient.

Recently, swirling fluidized beds are reported to exhibit excellent solid-air contact and making them ideal for processes involving heat and mass transfer such as drying. Unlike the existing fluidized bed systems, the swirling fluidized bed (SFB) provides swirling motion inside the bed apart from fluidization [2]. In the SFB system the fluidizing medium enters the bed at an inclination to the horizontal directed by a suitable design of a distributor [3]. Figure 1.2 shows the schematics of the SFB system.

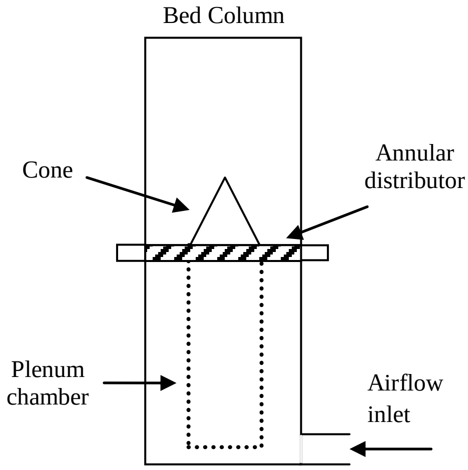

Figure 1.2: shows the schematic of the SFB system

1.1 Problem Statement

Sponge media blasting process requires the use clean and dry media for surface preparation. During rainy season, all the scattered sponge media used in the process (during blasting) are soaked in rain water. This becomes a problem to the blasting process since the sponge media are recycled to reduce the material inventory during blasting. Another arising problem is during retrieval of the media after blasting it contains foreign particles besides debris. Drawback of conventional drying method is not suitable for the high volume sponge media demand during blasting and to use new or unused sponge media is not favourable since it incurs additional cost, transportation time and storage space. Fluidized bed dryers are known to yield very high rate of heat and mass transfer and widely used for various drying processes. Among the promising variant of fluidized bed is the swirling fluidized bed dryer (SFBD). As reported in the literature [4, 5, 6], SFBD is capable in providing vertical and horizontal momentum inside the bed which allows vigorous mixing and high degree of solid-gas contact which is ideal for drying. Thus, it is proposed here drying of wet sponge media using the SFBD. Experimental investigation and thin layer modelling were carried out in the SFBD to evaluate the drying kinetics of sponge the media.

1.2 Objective

The objectives of this study are:

(a) to examine the basic hydrodynamic characteristics of sponge media in a swirling fluidized bed

(b) to investigate the drying characteristics of sponge media using a swirling fluidized bed dryer

(c) to model the sponge media drying process using thin layer models available in the literature

1.3 Scope of Study

To achieve the objectives above, the following scopes were outlined:

a) Industrial sponge media was provided by Deleum Primera Sdn. Bhd with average diameter, d_m, of 4.514 mm

b) Basic hydrodynamics study of both dry and water laden sponge media including minimum fluidization velocities, minimum swirling velocities, distributor and bed pressure drop and regimes of operation

c) Batch drying experiments with bed loads of 0.5 kg, 0.75 kg and 1.0 kg with drying temperature of 80°C, 90°C and 100°C, in accordance to the requirement of industry

d) The drying characteristics include moisture content against drying time, moisture ratio against drying time, drying rate against moisture ratio and calculation of effective diffusivity

e) Thin layer modelling for falling-rate drying period using Henderson and Pabis model, Logarithmic model, Modified Henderson and Pabis model, Newton model or Lawis model and Verma et al. model

1.4 Significance of Study

The findings from this study enable the determination of viability and performance of sponge media drying in a SFBD system. It will also facilitate the up-scaling and development of an actual SFBD system for industrial use. This will encourage the utilization of environment-friendly technologies in the surface preparation industry since this method solves one of the drawbacks in using sponge media mainly to save drying time process. On top of that, productivity in the industry will be increased with better safety aspects during operation.

1.5 Thesis Organization

The first chapter gives an introduction to the present study by highlighting the fundamental aspects of sponge media drying, objective and scope of this study. In the second chapter, a review on related studies to this thesis is summarized. In the third chapter, experimental set-up was elaborated in detail while chapter four present and analyzes all the findings from experimental work and modelling. The thesis is concluded in chapter five with recommendation for future studies.

CHAPTER 2

LITERATURE REVIEW

2.0 Chapter Overview

This chapter gives an insight on the fundamental aspects of drying and also reviews previous studies related to the present study. The important aspects of fluidization were also highlighted in the light of proposed drying technique i.e. swirling fluidized bed dryer (SFBD). Utilization of thin-layer models in predicting drying kinetics was also discussed.

2.1 Energy Consumption in Drying

In various industries, a large part from the total energy use is spent in drying. Production of wood products for instance, has the highest energy consumption with 70% of total energy spent, followed by textile fabrics with 50%, pulp production with 33%, paper with 27% and food and pharmaceutical was around 15% as shown in Figure 2.1. Energy spent for drying varies between countries and ranges between 15-20% of the total energy consumption in industry [7, 8, 9].

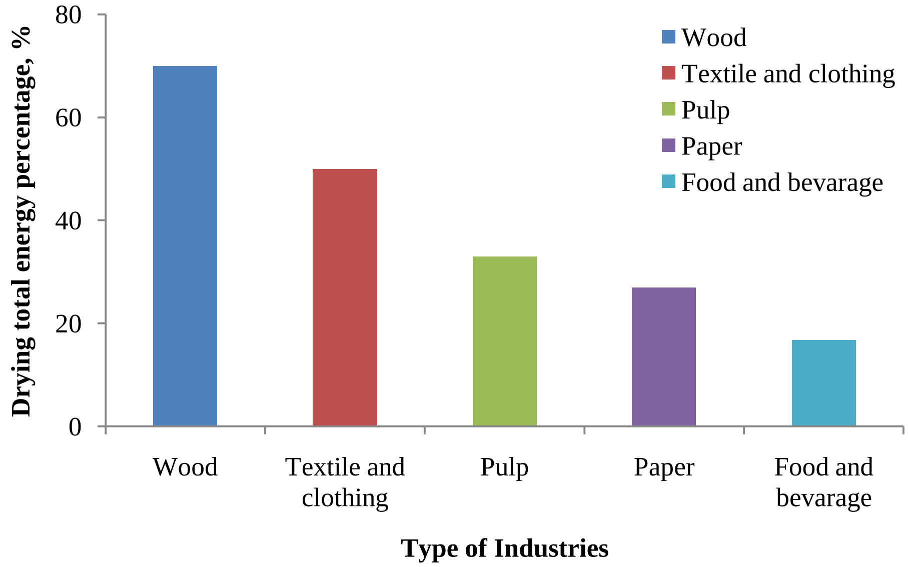

Figure 2.1: Percentage of energy used for drying for different industries [9]

The energy efficiency in the drying process was affected by various factors, for instance the evaporation rate, steam consumption and energy uptake by other processing units. Energy efficiency is defined as the ratio between the total energy required for evaporating water from the product and the total amount of energy spent to the system [7].

Considering the given energy efficiency values it is a challenge to work on the development of innovative dryers with a high drying rate, high energy efficiency, low investment and operational costs, and feasible for low and medium drying temperatures [10]. Many improvements from innovation and research in drying technology took place since decades ago but breakthrough solutions with respect to the energy efficiency were limited. Innovation in drying technology tends to reach a saturation level as reported [11] and a further significant reduction in energy consumption seems difficult to achieve.

2.2 Fundamentals of Drying

Drying is a process of removing or separating moisture from wet a material thermally. Although the driving force for drying is moisture difference, drying often carried out using hot air supply as heating medium to enhance the moisture transfer rate from the wet material. Drying may also be viewed as either a preservation technique or as a manufacturing step and in many cases performs both functions simultaneously [12, 13]. Drying process of wet particles consist two processes which occur simultaneously [14]:

a. Energy transfer (mostly as heat) from the surrounding environment to evaporate the surface moisture.
b. Internal moisture transfer to the surface of the solid and its subsequent evaporation due to previous process.

Energy transfer as heat from the surrounding environment to the wet particles or solids can exist as a subsequence of convection, conduction, or radiation and in some case as a combination of these effects. Generally, heat is transported to the wet solid surface and then to the internal solid body. In the initial stage of drying, moisture evaporate as vapour from the material surface, depending on the temperature, humidity and velocity of the air, exposed surface area, and pressure. Then, the movement of moisture internally within the solid is a function of the physical nature of the solid, the temperature, and its moisture content. In a drying operation, any one of these processes may be the limiting factor governing the rate of drying, although they both proceed simultaneously throughout the drying cycle. Method of moisture transfer can be occurring in any following mass transfer condition as below:

i. Liquid diffusion, if the wet solid is at a temperature below the boiling point of the liquid,
ii. Vapour diffusion, if the liquid vaporizes within material,
iii. Knudsen diffusion, if drying takes place at very low temperatures and pressures, e.g., in freeze drying,
iv. Surface diffusion (possible although not proven),
v. Hydrostatic pressure differences, when internal vaporization rates exceed the rate of vapour transport through the solid to the surroundings,
vi. Combinations of the above mechanisms.

Since the physical structure of the drying solid was subject to change during drying, the mechanisms of moisture transfer may also change with elapsed time of drying.

2.2.1 Process 1: External Conditions

The external condition variables are temperature, humidity, velocity and direction of air, the physical form of the solid, the desirability of agitation, and the method of supporting the solid during the drying operation.

External drying conditions are especially important during the beginning of drying process when unbound surface moisture is removed. Surface evaporation is controlled by the diffusion of vapour from the surface of the solid to the surrounding atmosphere through a thin film of air in contact with the surface. Since drying involves the inter-phase transfer of mass when a gas is brought in contact with a liquid in which it is essentially insoluble, it is necessary to be familiar with the equilibrium characteristics of the wet solid. Also, since the mass transfer is usually accompanied by the simultaneous transfer of heat, due consideration must be given to the enthalpy characteristics [12, 14].

2.2.2 Process 2: Internal Conditions

When heat is transferred to a wet solid, a temperature gradient develops within the solid while moisture evaporation occurs from the surface. This produces a movement of moisture from the inside of solid to the surface, which occurs through one or more mechanisms, namely, diffusion, capillary flow, internal pressures set up by shrinkage during drying, and in the case of indirect (conduction) dryers, through a continuous and progressive occurring vaporization and re-condensation of moisture to the exposed surface. An appreciation of this internal movement of moisture is important when it is the controlling factor, as it occurs after the critical moisture content, in a drying operation carried to low final moisture contents. Variables such as air velocity and temperature, which normally enhance the rate of surface evaporation, are of decreasing importance except to promote the heat transfer rates. Longer residence times and higher temperatures where permissible become necessary. The temperature gradient occurring in the solid will also create a vapour–pressure gradient, which will in turn result in moisture vapour diffusion to the surface; this will occur simultaneously with liquid moisture movement [12, 14].

2.3 Drying Techniques

A large number research and innovation on the types of dryers and drying methods were reported in the literature. Most of them were application specific and usually cost and efficiency are the main criteria in the dryer selection. Drying methods may range from conventional sun drying to various industrial drying types as follows.

2.3.1 Solar Drying

Solar drying is the simplest and cheapest drying technique but also associated with low efficiency. This is due to the dependence on many parameters such as humidity, air flow in the surrounding, daily temperature, the shape and size distribution of the wet solids and many more. Sun drying also difficult to control and hence result in necessity of larger area, longer drying time and the final product may be contaminated from dust and insects and suffer from enzyme and microbial activity.

2.3.2 Hot Air Drying

When hot air is in contact with the wet material to aid heat and mass transfer; convection is mainly involved. Two important aspects of mass transfer are the transfer of water to the surface of the material that is dried and the removal of water vapour from the surface. The hot air dryers generally used for the drying of piece-form fruits and vegetables are cabinet, kiln, tunnel, belt-trough, bin, pneumatic and conveyor dryers. Energy source to heat the air would be electricity or renewable energy resources such as solar and geothermal energy.

2.3.2.1 Cabinet Dryer

A cabinet dryer can be a small batch tray dryer. Heat from the drying medium to the product is transferred by convection. The convection current passes over the product, not through the product. It is suitable for drying of fruits, vegetables, and meat and its product. The main feature of a cabinet dryer is its small size and versatility. The main problem with cabinet dryer is difficulty in even distribution of heated air over or through the drying material.

2.3.2.2 Pneumatic Conveyor Dryers

Pneumatic conveyor dryers are generally used for the drying of powders or granulated materials and are extensively used in the making of potato granules. The feed material is introduced into a fast moving stream of heated air and conveyed through ducting of sufficient length to bring about desired drying. The dried product is separated from the exhaust air by a cyclone or filter.

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